LIGHT MODULAR CONSTRUCTION: ANALYSIS OF THE RELATIONSHIP BETWEEN MODULAR CONSTRUCTION SYSTEM AND SPACE LAYOUT IN SOLAR HOUSES FROM 2005 AND 2007 SOLAR DECATHLON COMPETITION.

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ABSTRACT

Present and future research will be oriented towards both industrial construction techniques and sustainability, and in this sense combination of mass production and sustainable houses is of a special relevance. Modular construction is a very successful building method in some countries such as Japan and U.S.A., and could be easily applied in solar houses production. In this way it is worth to refer to Solar Decathlon competition, promoted by the U.S.A. Department of Energy, as one major laboratory of solar house prototypes, most of them being modular homes.

As a progress report of modular construction applied to solar houses research, whose first paper was released at “II Jornada de Investigación en la Edificación EUATM”, Madrid 2008, in this study relationship between the modular system and space layout of solar houses from Solar Decathlon 2005 and 2007 are explored. This research will allow for a new open understanding of spatial design of each house regarding the influence of the modular construction type employed on them. It actually is an essential Knowledge to discover which the spatial and formal possibilities provided by these systems are, what in fact will be invaluable for future designers and builders. In a further stage a full set of construction design criteria will be obtained for their application to solar houses construction.

1.- Introduction

Present and future research will be oriented towards both industrial construction techniques and sustainability, and in this sense combination of mass production and sustainable houses is of a special relevance. Modular construction is a very successful building method in some countries such as Japan and U.S.A., and could be easily applied in solar houses production. In this way it is worth to refer to Solar Decathlon competition, promoted by the U.S.A. Department of Energy, as one major laboratory of solar house prototypes, most of them being modular homes. In each edition, 20 prototypes of houses are built and transported to the Washington mall. These examples give us an important research platform of the light modular construction in which we can obtain important construction criteria.

2.- Objective

As a progress report of modular construction applied to solar houses research, whose first paper was released at the previous edition of the current congress [1] by the authors, this research has as a main aim to study the relationship between the

modular system and space layout of solar houses from 2005 and 2007 Solar Decathlon competition.

3. Methodology

According to the classification shown in the previous report [1], first of all we describe three categories of modular construction, and then two more categories, that even though they do not belong to the modular construction category, they were used in the solar houses of the competition too. The three categories of modular construction cited above are:

1. Single unit.
2. Attached units (attached or stacked depending on the relationship, vertical or horizontal).
3. Multiple section units.

The other two categories of no modular homes are:

4. kit.
5. Panelized.

Alter that, eighteen houses from the Solar Decathlon Competition 2005 and twenty from the 2007 edition, have been classified, according to the criteria exposed previously, obtaining the amounts and percentages of each category. That will allow us to know the level of use of each system, as a valuable information in order to compare it with other results and so obtain the selection criteria more suitable for each house.

The second stage of this research has been devoted to the study and classification of the spatial organization of the houses' projects from the competition. In order to do that, four categories of spatial layout have been proposed:

1. Linear spatial layout.
2. Non linear single space layout.
3. Functional spatial layout.
4. Branched spatial layout.

With these criteria, we have selected the houses which belong to each category and they have been put in a chart for a better visualization. The quantity according to each type and the percentage out the thirty eight analysed projects will be shown in the chart. This will allow us to know the level of use of each spatial layout and will be a valuable information in order to compare them with other results, especially the modular system to check the spatial versatility of each type.

4.- Results

We have made a final chart, with de data obtained in the modular system and spatial layout, which links both criteria, expressing quantity and percentage. Then, we have got a global information of the combined use of the two criteria in the construction of solar houses, in order to analyze and recognize the construction systems more used and to extract valid criteria for a later utilization in the project of this kind of houses.

5.- Modular construction system used in the houses of the Solar Decathlon Competition 2005 and 2007.

5.1.- Definitions

According to the modular classification that has been proposed in the first report [1], we will classify the thirty eight prototypes of houses according to the following categories:

• **Single Unit**: they are based in a three-dimensional single unit transportable in a single truck. (fig. 4).

• **Multiple section units:** They are based in the addition of several units whose spatial identity disappear in the final volume. (fig. 1)

• **Attached units:** They are based in the horizontal association (attached) and/or vertical (stacked) of several three-dimensional units, which identity is recognizable in the final volume. (fig. 2)

We can add two more categories to the previous classification, that although they do not belong to the three-dimensional module sector, they can complete all the field of industrial solutions used in the assembly of these solar houses:

• **The kit:** It is a coordinated set of small parts, highly industrialized which allow a very easy transportation, due to its size and a very quick and easy assembly by low skilled staff. (fig. 3).

• **Panelized:** This construction system consists of plane elements or panels, that simplifies the transportation compared to the three-dimensional modules, providing better finished elements and so, a quicker assembly. (fig. 3)

5.2.- Module system classification.

fig. 1. Multiple section units classification.

fig. 2 Attached units classification.

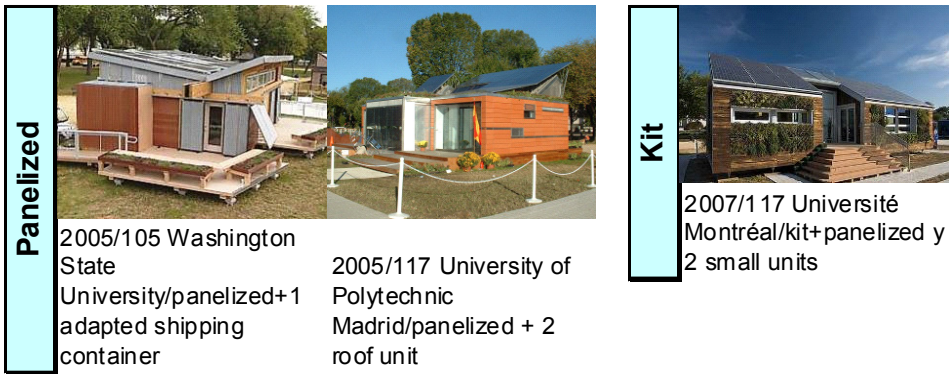


fig. 3. Panelized and kit classification.

fig. 4 Single unit classification.

5.3.-Comparative table of the modular system.

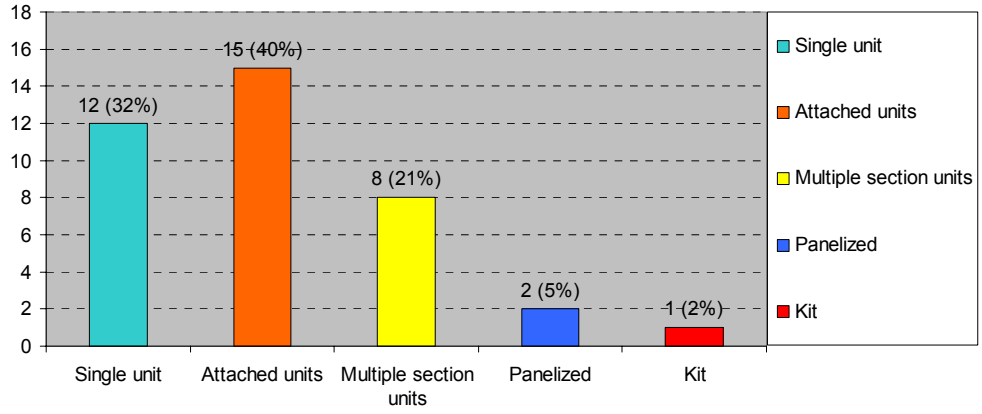


Table 1 Charts, values and percentages of the modular system. Source: own file.

5.4. Preliminary conclusions.

Alter classifying the thirty eight prototypes applying the modular classification exposed in 5.1 paragraph, the figures in the 5.2 paragraph (fig. 1, 2, 3 and 4) and the chart in the previous paragraph (table 1), we can verify that the modular system more used is that of attached units with a 40%, followed by the single unit with a 32% and the multiple section units with a 21%. With a very little use we have the panelized unit with a 5% and the kit unit with a 2%.

We can observe that the system most used is the attached one (fig 2), because it probably is the one which satisfy the most favourable conditions about weight and transport width. We will need to use a crane with no high tonnage and normal

transportation, respecting the maximum widths by road without asking for special permission. The assembly time is longer than the single unit one but without excessive joints, as the number of units can vary between two and four, although there is one of six units.

The following most used system is the single unit one (fig 4), because it usually don't have any joint and probably the assembly time is shorter, and the regulations of the competition give only a few days to do it. Often, there is no need to use a crane due to they usually incorporate a trailer with wheels.

Following, we find the multiple section unit one (fig. 1), which maybe has the most comfortable transport, and can require or not the use of a crane.

Probably, the fact that the less used system is the panelized and the kit ones (fig 3), is due to the great quantity of assembly tasks, joints to solve out in a few days, and probably the worse finish quality, due to the fact that all the assembly work must be done in situ. Although they benefit with an economic transportation and they do not use high tonnage cranes.

6.- The spatial organization used in the houses of the Solar Decathlon competition, 2005 and 2007.

6.1.- Definitions

The rules of the Solar Decathlon competition define a kind of housing of 74.3m^2 and a volume comprise in a pyramid of 5.5m high, in order to protect of shadows the neighbour houses, situated in an area of 500m^2, sited in the National Mall in Washington DC, in front of the Capitol. Each house encloses a sleeping area, dining area, study area, bathroom and kitchen. Through an analysis and a study of the houses that joined the event in the 2005 and 2007 editions, we propose the following classification based on the spatial layout:

• **Linear spatial layout:** Consists of a series of spaces related along a linear sequence of functions, setting up a single space. Its main characteristic is the constant wide that makes its perception as an elongated container (fig. 6).

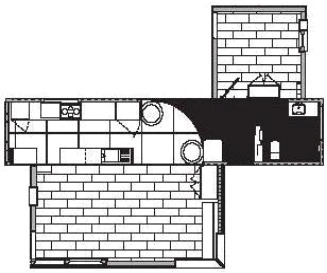
• **Single space layout non linear:** Consists of a flowing main space that houses the main functions of the house, in which the linear sequence is no dominant, nor a dimension above the other one (fig. 8).

• **Functional aggregation layout:** It consists in the aggregation of day spaces and night spaces in separate areas (fig. 7).

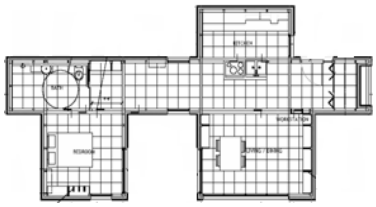
• **Branched spatial layout:** It consists in a linear space that serves as hall and corridor linking the rest of spaces (fig. 5).

6.2.- Spatial layout classification

Branched



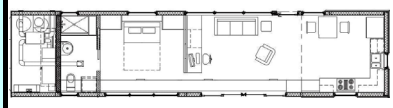
2007/111 University of Colorado at Boulr/2 adapted shipping containers +2 roof units



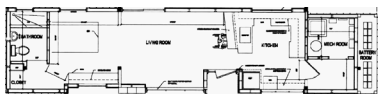
2007/114 Carnegie Mellon University/2 stacked units +3 attached units

Fig. 5. Branched layout classification.

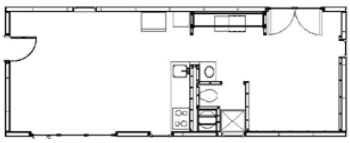
Linear



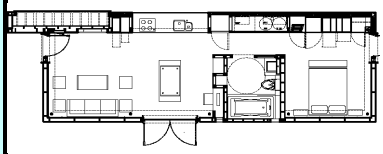
2005/101 Calpoly/1 unit



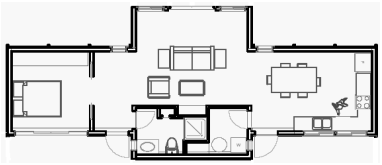
2005/106 University of Colorado/1 unit



2005/111 Cornell University/1 unit

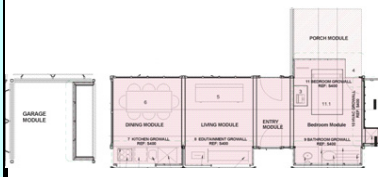


2005/115 Virginia Tech/1 unit

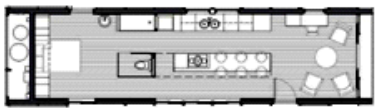


2005/120 University of Maryland/1 unit

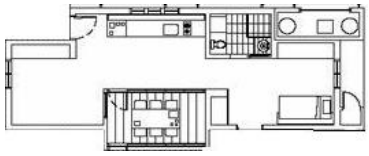
2007/102 University Polytechnic of Madrid/1 unit + 2 roof units+4 small units



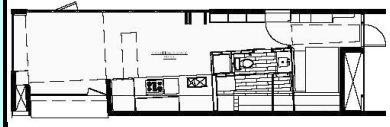
2007/104 Texas A&M/1 unit único+2 additional units



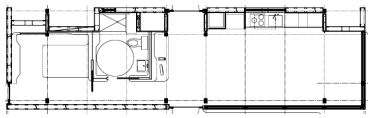
2007/105 University Texas Austin/1 unit



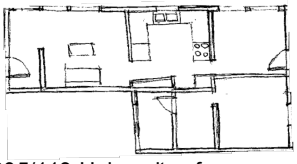
2007/108 University Cornell/1 unit



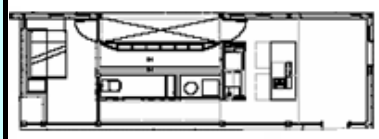
2007/110 Kansas/1 unit



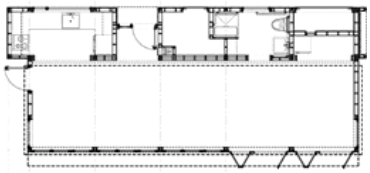
2007/113 Georgia Institute of Technology/1 unit



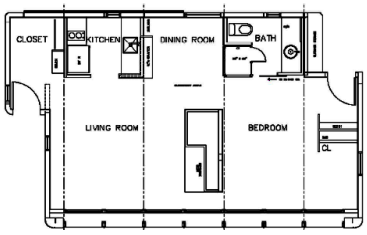
2005/113 University of Massachusetts Dartmouth/2 units



2007/103 University Puerto Rico/2 units



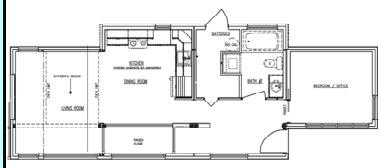
2007/120 University NYIT/ 2 units+1 roof units



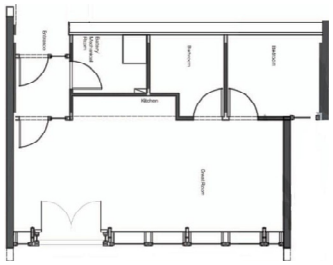
2005/108 University of Michigan/5 units

Fig. 6 Linear layout classification.

Functional aggregation

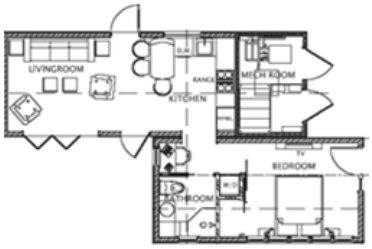


2005/103 University of Canadá/4 units

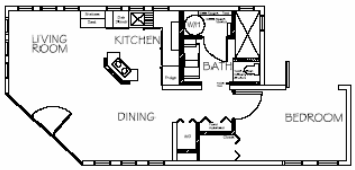


2005/114 Pittsburgh/2 units +panelized

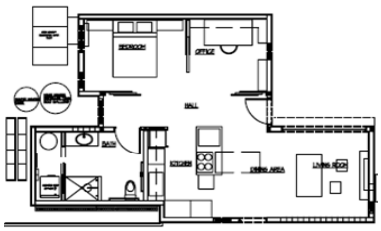
2005/119 New York Institute of Technology/2 units attached units + 2 roof units



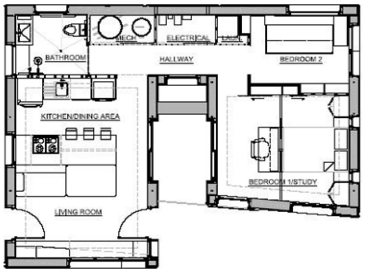
2007/101 Santa Clara University/2 units



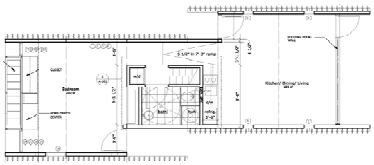
2007/109 University of Missouri-Rolla/2 units+panelized



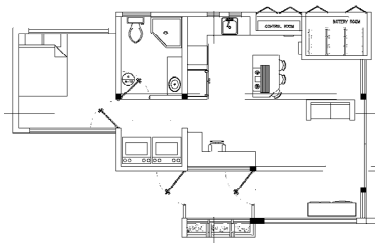
2007/116 Massachusetts Institute of Tecnology/4 units+unfolded roof units



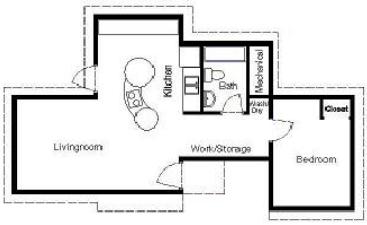
2007/119 Lawrence Technological University/3 units+3 roof units



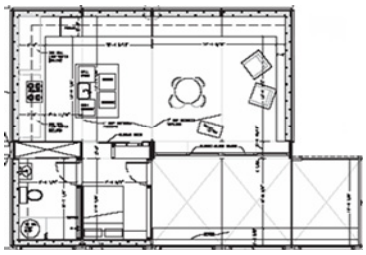
2005/102 Rhode Island School of Design/7 units+4 roof units



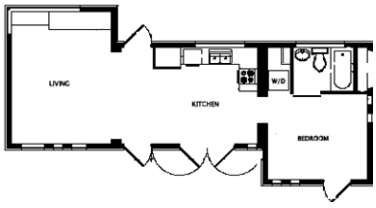
2005/107 University of Puerto Rico/ 4 units



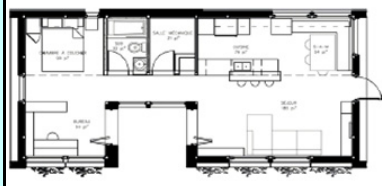
2005/109 Misouri Rolla/4 units



2007/106 University of Cincinnati/6 units



2007/118 University of Illinois at Urbana Campaign/3 units



2007/117 Université Montréal/kit+panelized y 2 small units

Fig. 7. Functional aggregation layout classification.

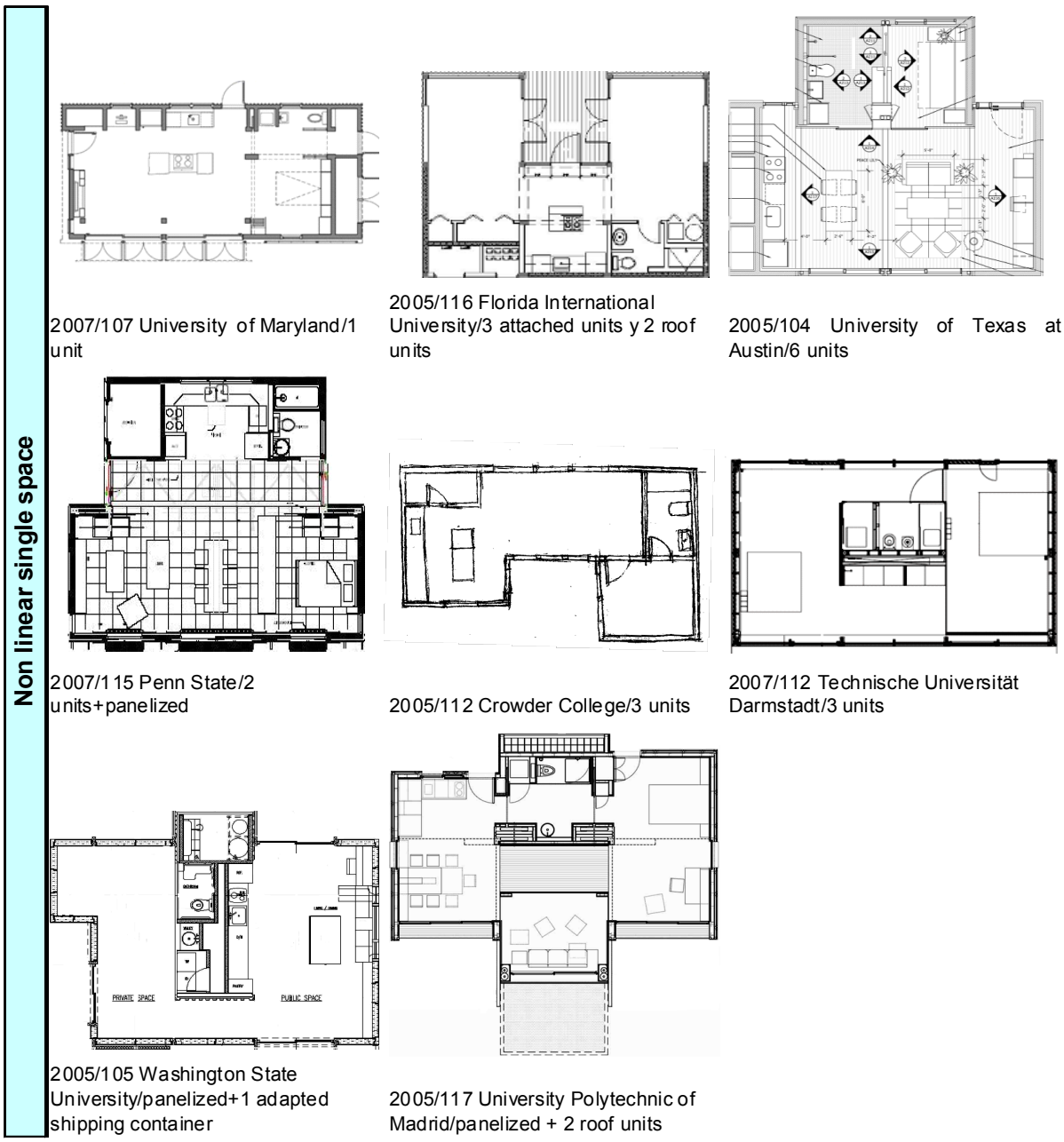


fig.8. Non linear single space classification.

6.3.- Comparing chart of spatial layout use

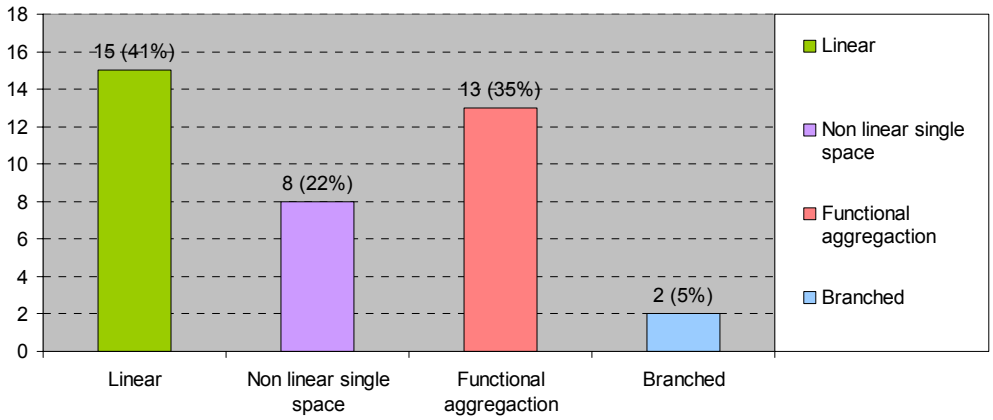


Table. 2 Graphs, values and percentages of every layout.

6.4. Preliminary conclusions

Alter classifying the houses according to the criteria of the spatial organization described above in the paragraph 6.1, 6.2 (fig 5, 6, 7 and 8), and the comparative table (table 2), we can assess that the spatial organization most used is the linear one with a 41%, following by the functional one with a 35%, and the single space non linear one with a 22%. The branched one has a very little use, having only a 5%.

Probably the selection of the predominant linear space is due to the simplicity of the proposal, giving by the choice of a certain modular construction system (fig 6). In the other hand, the functional aggregation one and single space non linear one are very used due to its spatial flexibility, achieved with modular construction systems. (fig 7 and 8).

7.- Relationship between the modular construction system and spatial organization used in the 2005 and 2007 Solar Decathlon houses.

In order to estimate the spatial possibilities of each modular system, we compare the data obtained in the modular system and spatial organization sections.

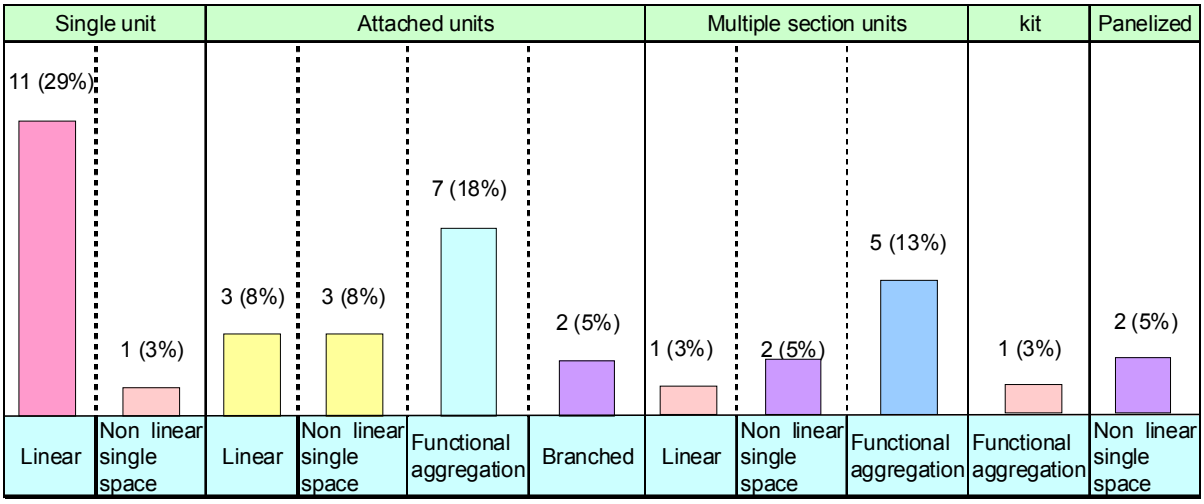


Table. 3 Charts and porcentajes between the spatial organiation and the modular system.

	Single unit	Attached units	Multiple section units	kit	Panelized
Linear	11 (29%)	3 (8%)	1 (3%)		
Non linear single space	1 (3%)	3 (8%)	2 (5%)		2 (5%)
Functional aggregation		7 (18%)	5 (13%)	1 (3%)	
Branched		2 (5%)			

Table. 4 Values and percentages comparing spatial layout and modular system.

8. Conclusions

From the preliminary conclusions extracted from the tables and charts shown previously, we can draw the following final conclusions:

1. The most versatile modular system is the attached unit one, due to the fact that all the spatial layouts described above can be built with this system. It has been the modular system most used, followed by the single unit one.

2. The second more versatile modular system is the multiple section unit one, where the only missed is the branched layout. It is the third system most used.

3. The single unit system is the third most versatile, in spite of its apparent rigidity has given place to two spatial types, being at the same time the second one more used.

4. Finally the two non modular systems, the kit and the panelized ones, have been hardly used and each of them have produced only one spatial layout.

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